PUPIL DIAMETER VERSUS TASK LAYOUT

Charles Edward Noel

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THESIS

PUPIL DIAMETER VERSUS TASK LAYOUT

by

Charles Edward Noel

September 1974

Thesis Advisor: G. K. Poock

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constricted condition (overloaded) in a non-compatible arrangement, it was found the constriction could be significantly reduced by switching to a compatible arrangement.

Pupil Diameter Versus Task Layout

by

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Lieutenant, United States Navy
B.S., University of North Carolina, 1968

Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

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I. INTRODUCTION

Recent studies of pupillary changes during mental activity suggest that variations of pupil size may reflect second-by-second variations of mental processing load with considerable accuracy. The occurrence of pupillary dilations during mental effort has long been known (Heinrich, 1896; Lowenstein, 1920), although it has attracted relatively little attention. Renewed interest was aroused by Hess and Polt (1964) and Hess (1965) who reported that the pupil of the eye dilates during the solution of arithmetic problems, and that the extent of dilation is related to the difficulty of the problem.

In a replication of this experiment, Hope (1971) found for correctly computed problems, increased pupil diameter occurred with increased mental activity as the degree of difficulty of the problem increased. For incorrectly computed problems, a decrease in pupil size was realized and the diameter continued to decrease as the difficulty of the problem increased. Hope hypothesized the constriction was due to a negative effect and was partially interpreted as a reflection of the subject's "disgust" in missing the correct solution. It was conjectured the mind was overworked and the subjects disliked the mental gymnastics. This "mental-block," which increased the negative affect and correspondingly decreased the mental activity, was realized as pupil constriction.

Kahneman and Beatty (1966) showed that pupil diameter is linearly related to the amount of material stored for immediate recall in a paced digit-span task. The subject's pupils were observed to dilate as he listened to a string of digits or words (called the loading function) and would constrict as he retrieved these items from short-term memory (called the unloading function). The degree of dilation was associated with both the length of the string of words or digits and the difficulty of the task. Kahneman and Beatty felt these results suggested that pupil diameter may have construct validity as a measure of the momentary "load" on subjects as they perform a mental task.

Kahneman and Beatty (1967) conducted an audio-tonal discrimination experiment which supported the validity of pupil measurements as an index of processing load. The subjects were asked to compare two tones and asked to decide if the comparison tone was higher or lower than the standard tone. The results showed the magnitude of pupil dilation increased with the difficulty of the discrimination task.

Pavio and Simpson (1968) conducted an experiment investigating the effect of an overt response indicating task fulfillment on pupil diameter. It was discovered that greater dilation occurred only in those conditions in which an overt response was required, in this case pressing a key and/or verbalizing a response. They concluded that pupillary dilation is enhanced when an overt motor response is required.

Peavler (1969) obtained pupil measurements on subjects while they were engaged in processing either five, nine, or thirteen digit lists for immediate recall. Dilation patterns, corresponding to the presumed processing effort, and recall performance scores differed for two rates of stimulus input. Peavler felt information overload resulted in pupillary patterns which suggested that processing efforts were suspended when storage capacity was knowlingly exceeded.

In conducting a second set of experiments, Peavler, demonstrated that correct recognition of an arbitrarily designated stimulus from an array of similar stimuli is accompanied by reliable dilations. Presentation of identical stimuli under conditions not requiring processing or attending failed to elicit such a response. Peavler summarized his results by stating that individual differences in initial pupil size may provide predictive indicators of behavioral performance in tasks requiring attending to and processing of stimulus information.

Poock (1973) presented subjects with a serially presented four-alternative, forced-choice task. One of the four equally likely one-digit numbers was presented, and the subject responded by pressing a button corresponding to the number. These numbers were presented at 50%, 75%, 100% and 125% of the subjects maximum-processing capacity. This maximum capacity was established by allowing the subjects to respond as rapidly as possible to 50 practice trials. The results of this work indicated that pupil diameter was significantly greater than a baseline diameter when subjects were required

to process information at 75 and 100% of their maximum capacity. However, when subjects processed information at a rate above their maximum capacity, the pupil constricted significantly below the baseline diameter. Poock felt that pupil diameter may be a parameter which would identify points in time where mental overload could occur in a workers job.

II. BACKGROUND AND PURPOSE OF THE EXPERIMENT

Poock (1973) stated:

> The results of this investigation suggest that pupillary diameter may be a measure which could be used as an indicator of mental overload, because severe constrictions of the pupil occured only when S's were required to process information at a rate above their maximum capacity. It may be possible to analyze layout and design of work places by examining the pupil diameters of a group of people working at the same job. By observing those points in time when the workers' pupils contract below their normal baseline level, one might then identify what the workers were doing. Observation of the physical activities required at that point in time may indicate too many simultaneous actions are required of the operator, poor layout, etc. Following any changes in design, one might again examine the operator's pupil diameters for constriction below a baseline level. If prior pupillary constrictions were now absent, one might be able to infer that mental overload has been eliminated.

Thus the purpose of the present experiment is to design a laboratory controlled task, and by changing the layout of the task, attempt to alleviate an existing overload condition.

III. EXPERIMENTAL PROCEDURE

A. APPARATUS

Measurements of pupil diameter were taken and recorded by a Space Sciences Model 831D television pupillometer. The pupillometer employs a closed circuit television camera focused on the subject's eye which is illuminated by a low-intensity, near infrared source. The light source illuminates the eye without discomfort or distraction to the subject, as well as producing a signal that is electronically processed to measure and display the pupil diameter.

A continuous real-time charting of the pupil diameter was provided by a chart recorder which is an integral part of the pupillometer system. In addition, at critical points, instantaneous readings were manually recorded from an analog panel meter on the front of the recorder. The normal range of the pupil diameter is from 2.9 to 6.5mm.

The stimuli used in the experiment were a bank of four equally likely lights. The lights were varible intensity standard white peanut bulbs. Across the front of the bulbs were placed correspondingly red, yellow, blue and green lenses. Directly below the lights were two banks of colored contact buttons. The arrangement of the buttons were in a compatible and non-compatible sequence.

The equipment was electrically switched from a compatible to non-compatible mode. Compatible and non-compatible

arrangements are shown in Figure 1. The subject would depress the button corresponding to the input light stimulus. Even in the non-compatible mode the subject had to press the same color response button in order to shut off the stimulus light. The stimuli presentation rate was controlled by the experimentor through the use of a paper tape reader The experimentor varied the speed of the tape reader and thus the rate at which the subject must respond.

The experiment was conducted in an environmental chamber, where outside noise and incidental lighting were controlled. The luminance of the stimuli lights was carefully controlled in order to avoid a light reflex contamination of the data. The use of a light meter was employed to accomplish better control of experimental lighting fluctuations.

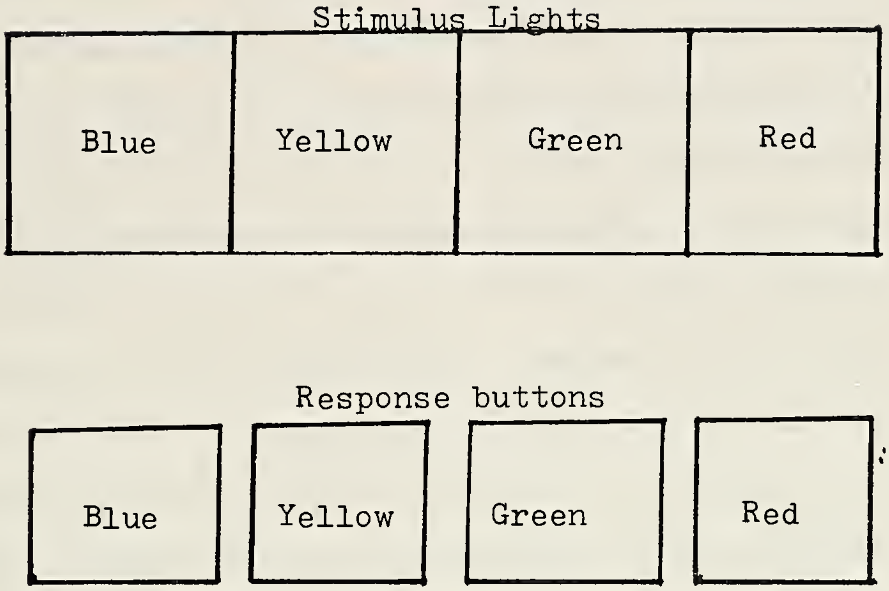
B. METHOD

Prior to the initiation of the experiment each subject was briefed on the equipment to be employed and to a degree on the history of pupillometry. The experimentor hoped to alleviate any anxiety the subject may have and to make the subject feel a vested interest in the experiment.

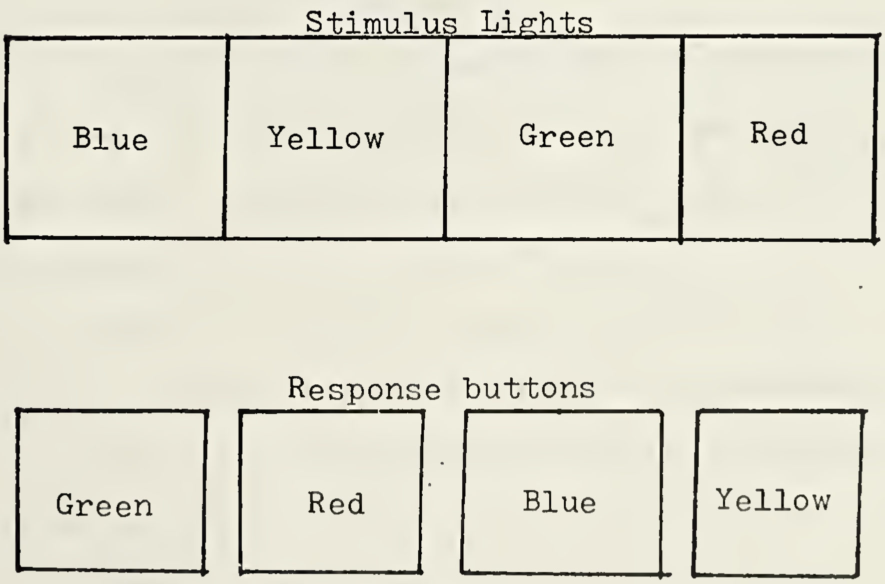
The subject was then seated and verbal instructions were given pertaining to what the presentation would be and how a response was initiated. Also warnings were given that the subject must minimize head movements. The subject's chin was placed in a padded chin rest, and the subject was then allowed two minutes in the compatible arrangement and two minutes in the non-compatible arrangement.

Figure 1

Compatible



Non-Compatible



Subjects were then asked if they felt at ease with the equipment. In all instances the subjects answered in the affirmative.

The subjects were then asked to focus on a lighted presentation light and a baseline reading was taken on the subject's pupil diameter. The subjects were then run through the first stage of the experiment. In the compatible arrangement (the response button corresponding to the stimulus light is located directly beneath it) the subject responded to an increasing presentation rate. The rate was stepped up in increments of .1 lights per second, this presentation rate is directly transferable to bits of information per second based on the fact the four equally likely stimuli lights represent a two bit task. The time between incremental increases was 15 seconds. The experiment was initiated at .5 lights per second and increased until the subject revealed an overload condition, i.e. constriction below the initial baseline diameter.

The pupil diameter was recorded at each presentation rate level, both manually and graphically. The manual recording was taken just prior to initiation of the next presentation level.

Following completion of the compatible task the equipment was switched to the non-compatible arrangement (response buttons not located directly below the stimulus light) and the presentation rate was decreased to .5 lights per second. Again the presentation rate was increased at 15 second intervals until the subject revealed an overload

condition. When the overload condition was noted this time, the experimentor immediately switched to the compatible arrangement and maintained the same presentation rate in order to check if there was a change in pupil diameter. After 15 seconds the pupil diameter was noted and recorded.

Measurements that were taken for analysis were:

1. light presentation rate for compatible arrangement constriction.
2. light presentation rate for non-compatible arrangement constriction.
3. pupil diameter (pdn) in non-compatible constriction
4. pupil diameter (pdc) 15 seconds after the switch from non-compatible to compatible.

C. SUBJECTS

Subjects for the experiment were ten volunteers, two female and eight male, between 12-36 years of age, with no known mental or physical disorders. None of the subjects wore glasses. All subjects appeared to be alert and were eager to participate in the experiment. The male subjects all had been previously tested for color blindness. No incentives or gratuities were paid the subjects.

IV. RESULTS AND DISCUSSION

The baseline data obtained for this investigation indicated the relatively stable level of the subject's pupil diameter while looking at a control light. For recording purposes it is the maximum diameter attained during the period of measurement.

This was consistent with the other measures of pupil diameter taken. For each 15 second interval the pupil diameter utilized was the maximum diameter attained during that interval. Although there appears to be many ways of arriving at a diameter during a time interval, the method of maximum dilation is widely accepted throughout previous literature.

The maximum presentation rate in both the compatible and non-compatible situation was that rate which caused the maximum diameter of the pupil not to exceed the baseline diameter for an entire presentation interval. As explained earlier these time intervals are 15 seconds long and are easily identifiable on the chart recorder, which has timing marks of .2 seconds and major intervals of one and fifteen seconds.

The stated purpose of this experiment was to see if by changing the layout of a task, the experimentor could alleviate a mental overload created by the task. This problem was addressed from two viewpoints.

First the experimentor forced the subject into an overload condition in the compatible arrangement and then again the subject was overloaded in the non-compatible arrangement. By comparing the amount of presented information the subject was processing, it was hoped a conclusion could be drawn about the two types of arrangements.

As is shown in Table I, the subjects were able to process more bits of information per second in the compatible arrangement than in the non-compatible arrangement. By applying a Wilcoxen matched-pairs signed-ranks test to the data, it was found that the presentation rate at the time of overload in the non-compatible condition was significantly ($p < .025$) lower than in the compatible arrangement.

In the second approach to the problem the subject's pupil diameter was measured during the overload condition in the non-compatible arrangement and again during the fifteen seconds following the switch to the compatible arrangement. These two readings are again shown in Table I. Again applying a Wilcoxen matched-pairs signed-ranks test to the data, it was found that the pupil diameter in the non-compatible arrangement was significantly ($p < .025$) smaller than pupil diameter in the compatible arrangement.

Thus, the results of this investigation infer that the mental overload created by a task could possibly be alleviated by a more compatible arrangement of elements within the task.

The data as a whole tended to support Poock's (1973) interpretation of the pupil as an indicator at points in

BPD(mm) - Base Pupil Diameter
CIR - Compatible Information Presentation Rate at Constriction (Bits/sec)
NIR - Non-Compatible Information Presentation Rate at Constriction (Bits/sec)
PDN - Pupil Diameter during Constriction in Non-Compatible Condition (mm)
PDC - Pupil Diameter during Constriction in Compatible Condition (mm)

Summary of Results of Experimental Tasks

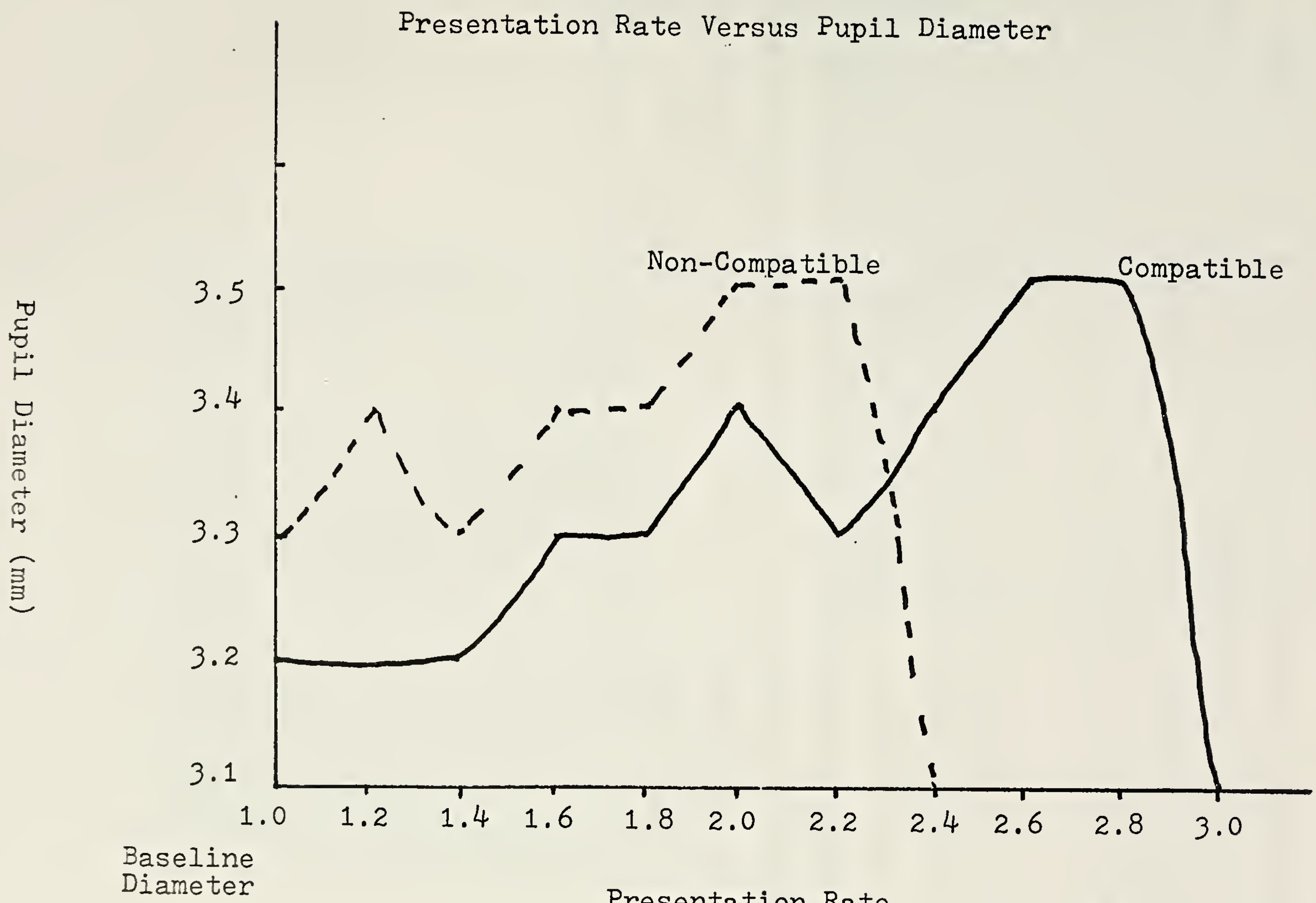
Subject	BPD	CIR	NIR	PDN	PDC
1	3.3	3.4	2.6	3.0	3.5
2	3.5	3.2	2.0	3.1	4.3
3	3.2	2.8	1.8	2.9	3.5
4	3.8	2.2	2.0	3.5	4.4
5	3.4	3.0	2.0	3.0	3.2
6	4.1	2.6	1.8	3.5	3.8
7	3.4	2.4	1.8	2.9	3.3
8	3.6	3.0	2.0	3.0	3.7
9	3.7	1.8	1.6	3.2	3.8
10	3.2	2.8	1.8	3.0	3.2

TABLE I

time of the overload condition of the subject. In Figure 2 a representative plot is made of one subject's pupil diameter versus presentation rate. Although the plot is only for one subject it is representative of the appearance of other subjects' plots. The subject's pupil tended to increase as the presentation rate increased and then would show a marked decrease at the time of overload.

Returning to Peavler's (1969) statement that initial pupil size may provide predictive indicators of behavorial performance in tasks requiring attending to and processing of stimulus information, an attempt was made to correlate this data's baseline pupil size and the eventual presentation rate at the time of pupil constriction. Applying a Kendall rank correlation coefficient test to the compatible data, it yielded a τ of -.3, which has a p=.146. Thus the data did not seem to support Peavler's hypothesis.

This experiment employed the vertical scanning technique as opposed to the conventional television scan which is horizontal. The advantage of the vertical scan is an insensitivity of the pupil measurement to lid and vertical eye movements. It was found, unless the eye has a fairly high fixation point which raises the eyelid and lashes out of the field of view, the horizontal scan may produce spurious pupil diameter data. It should be pointed out, that the vertical scanning technique is very sensitive to horizontal eye movements. But the experiment performed required only vertical eye movement and lent itself to



Presentation Rate Versus Pupil Diameter

Figure 2

the technique most effectively. The change over from the normal horizontal scan to the vertical scan is accomplished in the Space Sciences 831D model by the use of a mounting bracket included as standard equipment.

This investigator found, as have previous experimentors, that the pupillometer is very sensitive to the color of the subject's iris. It was very difficult to obtain an optimal crescent and black line on the monitor, when a subject had a light colored iris.

An area of possible continued study would be one of correlating the size of the pupil to the specific amount of information the subject is processing. Up until now most experimentors have observed the phenomenon occuring, but have not attempted to quantify the amount of information corresponding to the amount of dilation occuring in the pupil. This line of study would go far towards making pupillometry into a workable scientific tool.

APPENDIX A

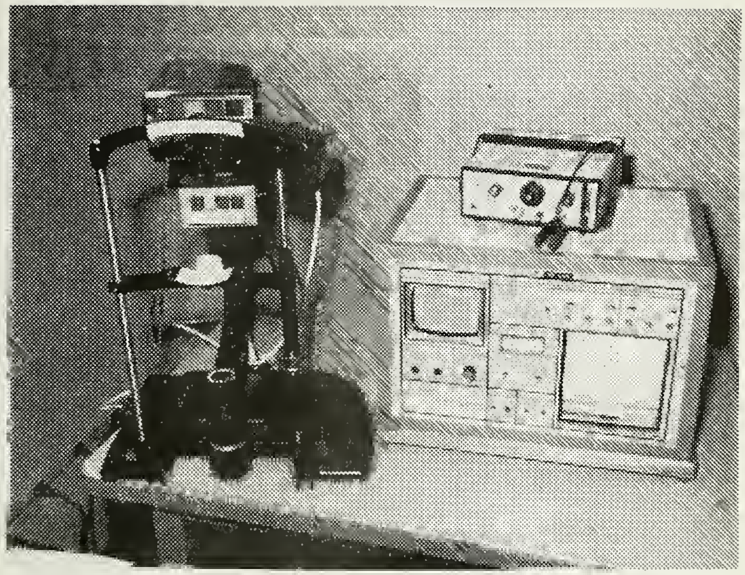


Figure 3, Pupillometer

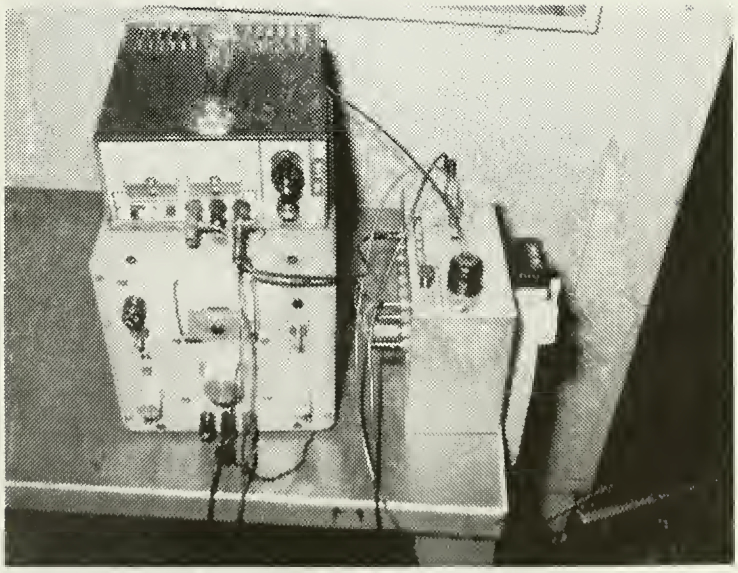


Figure 4, Step Counter

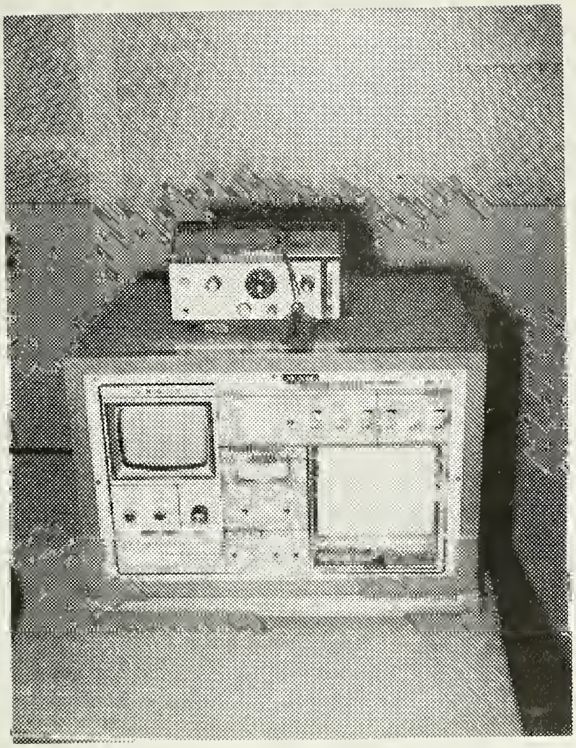


Figure 5

Step Counter Control

and Recorder

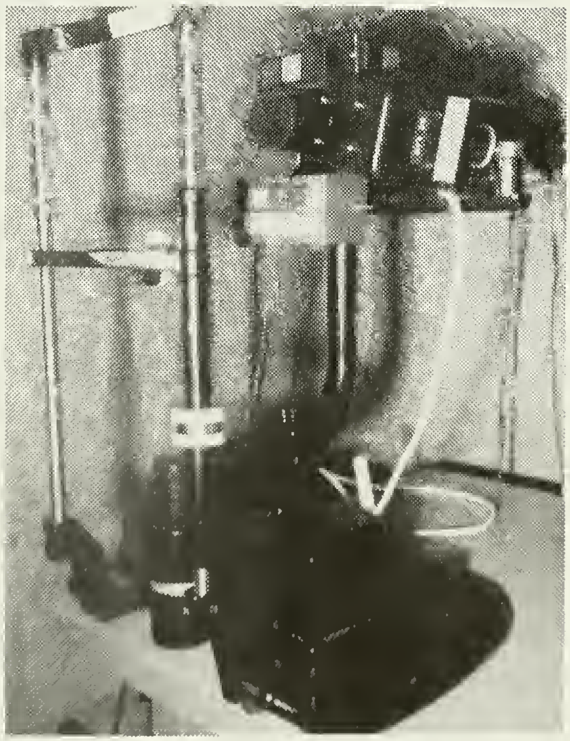


Figure 6

Head Mount and

Light and Button

Arrangement

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